RECTIFICATION OF THE OPAL COLD NEUTRON SOURCE CRYOGENIC SYSTEM

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ABSTRACT

The Cold Neutron Source (CNS) at ANSTO's OPAL Reactor had experienced repeated outages since 2009 due to failures in the cryogenic system. An extensive root cause analysis was initiated in May 2012, led by an ANSTO team that also involved knowledgeable external experts. At the conclusion of the investigation, a set of recommendations was released to address the identified contributing causes. A rectification program was established to implement the solutions. Cryogenic operation of the CNS, providing end users with cold neutrons, successfully returned to service in July 2013. Thanks to the unique stand-by operation mode of the CNS, irradiation activities at the reactor, as well as thermal neutron availability, had not been affected during the year-long investigation/rectification process. Some technical and operational aspects of the investigation, testing and engineering modifications are discussed in this presentation.

1. Introduction

The OPAL reactor at ANSTO is a 20 MW multi-purpose research reactor that conducts commercial production of medical and industrial radioisotopes and also provides high flux neutron beams to scientific experiments. The Cold Neutron Source (CNS) at OPAL employs 20 litres of sub-cooled liquid deuterium at an average temperature of 23 K as the moderator to generate cold neutrons [1, 2]. Commissioned in 2006, with a unique design feature of Stand-by Operation (SO) mode, it allows the reactor to operate at full power without the CNS at cryogenic temperature (NO mode). Although the SO mode seems irrelevant to cold neutron experiments, it has brought significant benefit to the OPAL reactor as a whole due to its multi-purpose nature, including availability to the thermal neutron experiments.

2. Failure History

A series of systemic faults developed in the CNS cryogenic system since its commissioning that resulted in prolonged, repeated outages [3, 4]. Until 2007, the turbo expander was subject to severe air contamination due to a design flaw in the helium compressor shaft seal. After the fault was corrected, the system was able to return to normal service in NO mode.

However, in July 2009, one of the two helium compressors had a mechanical failure. The damage to the screws in the compression chamber (conventionally called the air end in the compressor industry) was catastrophic. The air end had to be replaced, and the entire oil and helium circuits cleaned up, before the compressor could resume operation. Unfortunately, this was only the beginning of a series of compressor failures that seriously impacted on the CNS availability. Furthermore, ANSTO's own investigation had concluded that oil degradation during such kind of compressor failure would generate large quantities of contamination and consequently damage the turbo expander downstream [4].

While the CNS availability at reactor power was 100% from 2007 to 2009, it dropped to an unsustainable 66% from 2009 to 2012. The CNS user program was impacted and the neutron scattering community had to seek alternative access for a range of scientific projects.

Fig. 1 Helium Compressor used in the CNS Cryogenic System

3. Root Cause Analysis and Rectification

In 2012, CNS NO mode operation was suspended pending a thorough root cause analysis. The project was managed by ANSTO's own investigation team. Several external consultants with expertise in mechanical failures, cryogenics and cold neutron source operations were also engaged. The scope of the investigation included all aspects of design, operation and maintenance of the whole cryogenic system. All the CNS system data was scrutinized. A whole range of hypotheses was considered.

On the face of it, the compressor failure statistics was highly puzzling. The lifetimes ranged from "instant" (i.e. within the first 24 hours) to 23,000 hrs. The failures occurred in either compressor during NO mode, SO mode and even compressor self-circulating test mode. They occurred at reactor power as well as during reactor shutdown. The final symptom, however, was common to them all, that is, mechanical failure in the air end with substantial material loss from the screws which consequently led to blockage of the oil filter causing oil starvation.

After examining all the evidence, the ANSTO team made its preliminary finding: the oil temperature inside the compressors was too high to provide effective lubrication. To validate this finding, a test program was devised, where one of the in-situ compressors would be cooled with water from chillers that can accurately control the water temperature. The compressor was fully instrumented with temperature, pressure and flow sensors in the oil circuit as well as vibration sensors at the bearings positions around the air end. The aim of the test was to deliberately cause damage to the screws (brand new) by raising the oil temperature, and then stop the damage and stabilise the machine by lowering the oil temperature. Essentially, the test attempted to actively control the onset of the hypothesised failure mechanism. One of the critical devices used for the test was a magnetic filter, installed in the oil circuit. It was designed to catch the metal debris without blocking the oil flow, so the test could continue without the air end continuously deteriorating.

The test was a success and validated the root cause. The onset of screw damage could be triggered by raising oil temperature. The amount of metals debris trapped in the magnetic filter was clearly visible (Fig. 2). Significantly, as expected, the compressor could be stabilised by lowering the oil temperature and resumed normal service despite the mild damage.

The project then entered the rectification phase. The key action was to modify the OEM oil/cooling water circuits so that the oil temperature would not only be significantly cooler, but also controlled to a constant. The best way to achieve that was to replace the original heat exchanger by a more efficient third party product and add a control loop. The modification was completed on both compressors by June 2013.

In July 2013, the CNS was returned to service in NO mode, after 16 months of outage. Performance of the system during the first two reactor cycles indicates the compressors are stable, so is the turbo expander and the cryogenic power of the whole system.

Fig. 2 Metal debris (reflective flakes) trapped in the magnetic filter

4. Reactor Operation in SO mode

Thanks to the SO mode, the reactor had been able to operate at full power in accordance with the published schedule throughout the entire investigation and rectification process, achieving 265 days of operation from July 2012 to June 2013, even with a six-week major shutdown due to the installation a new neutron beam guide in the bunker. One of the compressors has a variable frequency drive (VFD) which allows its motor to run at a minimum of 60% of the full speed, which is adequate to sustain the SO mode. The reduced gas flow on that compressor meant that the oil temperature was sufficiently lower than at full load that screw damage would not occur.

5. Summary

We have described the year-long process ANSTO embarked on since mid-2012 to investigate and rectify a design flaw in the CNS cryogenic system compressors that have repeatedly and catastrophically failed since 2009. During this process, the SO mode has ensured uninterrupted reactor operation, hence supply of medical isotopes to the health community as well as the thermal neutrons to scientific experiments.

6. Acknowledgement

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7. References

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